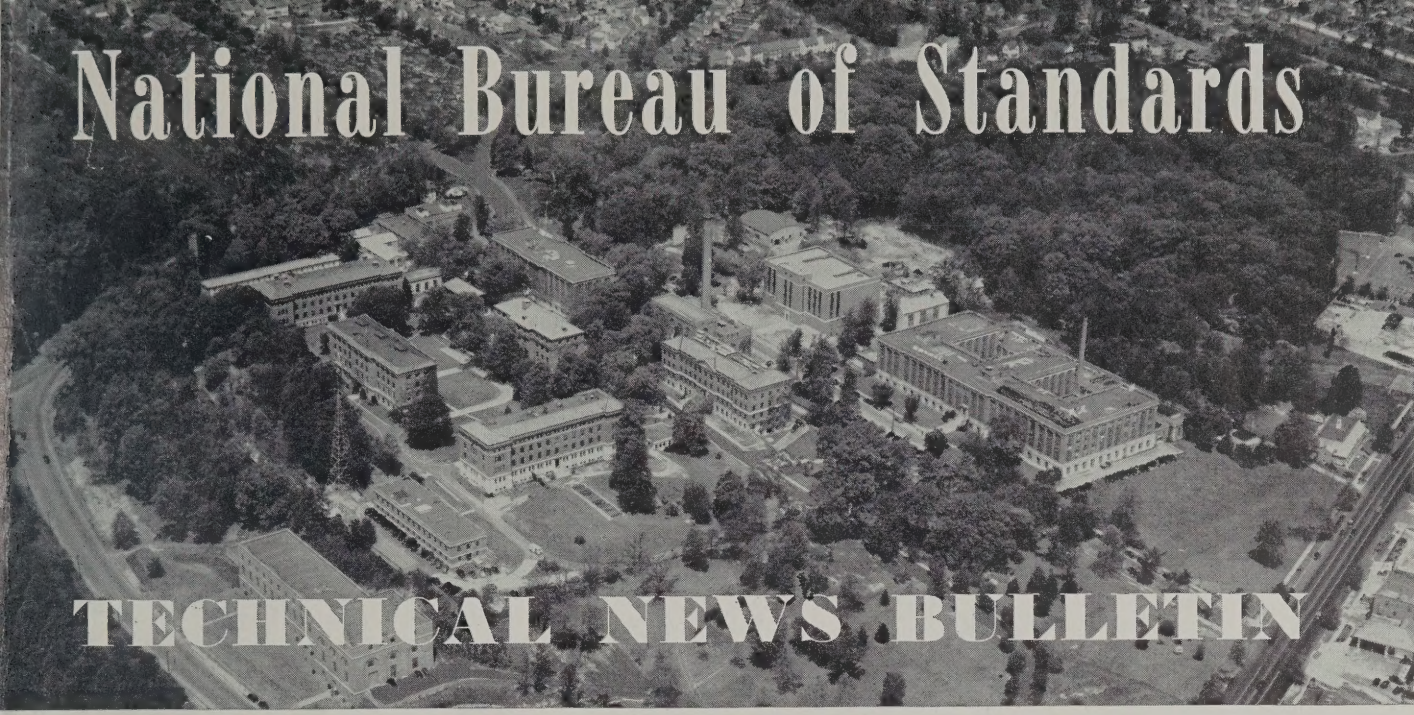


VOLUME 33 JANUARY 1949 NUMBER 1

# Color Perception of the Partially Color-Blind

When a color-blind person describes a red object as green, the question arises, does he see red, green, or some other color. In a comprehensive study of this problem at the National Bureau of Standards, Dr. Deane B. Judd has pieced together scattered evidence, combined it with established color theory, and derived a detailed and precise explanation to the phenomena of color perception of the partially color-blind person.[1] This work not only provides a more easily understood basis for the design of color-blindness tests, but it establishes for those who confuse red and green (red-green confusers) a tangible method for the analysis and better realization of their color perception.

About 2 percent of otherwise normal human males have this deficiency in color perception from birth. They often find their lives complicated by their inability to distinguish between red and green, and certain occupations are formally closed to them. Considerable interest, therefore, is aroused by the question, "What do red-green confusers see?" It is important not only to designers, administrators, and interpreters of color-blindness tests, but also to the three million American men who have to choose their careers with due regard to their sensory capabilities.

The question of what red-green confusers see is difficult to answer, because there is no well-defined connection between the language of the partially color-blind and that of the normal-sighted. During the last century, however, important discoveries have been made regarding color-blindness. Color matches established by a normal visual system have been found to hold, with minor exceptions, for red-green confusers. Two types of red-green confusers are now known to exist, both about equally prevalent: Deuteranopes, those who confuse purplish red with green; and protanopes, those who confuse red with a darker bluish green.

The relationship between protanopic and deuteranopic vision and normal color vision is revealed by sensitivity curves. Persons with normal vision have a three-part response that may be described by three such curves, whereas red-green confusers have only a two-part response. The short-wave response function for red-green confusers is the same as that for normal, but instead of requiring two different longer-wave response functions to describe their color matches, they need only one. The color confusions of protanopic vision can be described by means of the short-wave and the middle-wave function; those of deuteranopic vision, by means of the short-wave and the long-wave function.

Studies of the various types of confusion have gradually provided cumulative data on the perceptions themselves. Evidence of primary importance has been obtained from reports by men who have one normal eye and one red-green confusing eye. Eight such cases yielding definite data are on record. Another kind of evidence is provided by persons who have acquired the deutero-form of red-green confusion through disease of the eye and optic nerve. In addition, data may be obtained with the normal eye by stimulating the retinal zone 20 or more degrees away from the

[1] For further technical details, see Color perceptions of deuteranopic and protanopic observers, by Deane B. Judd, J. Research NBS 41, 247 (1948) RP1922.

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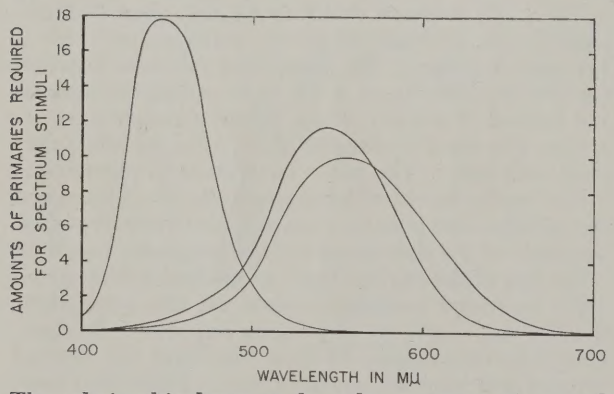
center. This retinal zone is also red-green confusing and exhibits the deutero-form of confusion. Evidence of all three kinds is in agreement, indicating that the color perceptions arising from red-green confusing retinal areas are black, white, yellow, blue, and blends thereof. The yellow is similar to what the normal eye perceives under ordinary conditions to belong to the spectrum at 575 millimicrons, whereas the blue corresponds to 470 millimicrons.

The usual designations of the sensitivity curves are violet, green, and red, for the short-wave, middle-wave, and long-wave curves, respectively. These designations indicate fairly well the color perceptions of the normal eye. They have sometimes been applied also to the pairs of curves characterizing the two types of red-green confusers and have led to the prediction that chromatic perceptions of protanopes are confined to violet, green, and blends of these two. Similarly, it has been predicted that the chromatic perceptions of deuteranopes are confined to violet, red, and their blends. Such designations must now be given up. When the sensitivity curves are used in pairs to describe the color matches of red-green confusers, the short-wave curve of the two should be designated blue; and the long-wave of the two, yellow.

The Munsell system of color notation, after many years' trial, is now widely accepted for describing color. This acceptance has arisen because the Munsell hue of a color correlates well with actual hue perceived by the normal eye. Similarly, Munsell value indicates the lightness of the color perceived; and Munsell chroma, how vivid it is to the normal eye. From the sensitivity curves it is possible to compute analogous color notations that will correlate well with the color perceptions of red-green confusers. This has been done for all of the colors (about 400) of the 1929 Munsell Book of Color for both types of red-green confusers. In all of these protanopic and deuteranopic Munsell notations there are only two hues, yellow (5Y) and blue (5PB). In tabulating the notations, the colors have been arranged in ways that should appear orderly to the red-green confuser. These tables show exactly which reddish and greenish colors are confused with colors of the light-dark, yellow-blue, two-fold, and the Munsell notation of each shows in complete detail what the deuteranopic or protanopic color perception is expected to be.




**The relationship between the color response of normal vision and the vision of partially color-blind persons (red-green confusers) is revealed by sensitivity curves. Three curves represent normal vision with its three-part response. Only two curves, however, are required to describe the vision of red-green confusers, the short-wave and the middle-wave for protanopes and the short-wave and long-wave for deuteranopes.**

Examples have been worked out to show how such tabular data may be of assistance in the design of color-blindness tests. Some color-blindness tests fail to separate those who have slight ability to distinguish red and green from those who have none. Not only does the present work provide a quantitative method for detecting and analyzing this distinction, but it also provides a means for the color-blind observer with two-dimensional color perception to relate his observations to the normal tridimensional system.

## Automotive Antifreezes

The essential properties of automotive antifreezes, together with practical suggestions for their proper use, are described in the new Bureau Circular 474, *Automotive Antifreezes.** This circular includes data on the performance to be expected of the different types of antifreezes as well as simple tests for distinguishing these types. It also tells how to prepare the automobile for antifreeze and when to replace the solution. Although designed primarily for the automobile owner, this publication should prove useful to testing laboratories and to prospective manufacturers of antifreezes.

*Circular 474 is available only from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at 15 cents a copy.


# TECHNICAL NEWS BULLETIN

U. S. Department of Commerce
Charles Sawyer, *Secretary*
National Bureau of Standards
E. U. Condon, *Director*

JANUARY 1949 Issued Monthly Vol. 33, No. 1

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# Minute Magnetic Patterns

In both input and output mechanisms for electronic digital computers, information in the form of coded pulses is commonly stored in magnetic media, such as wire or tape. This appears to be the most feasible method for feeding data to the high-speed computing machines now under development at the Bureau for the purpose of solving mathematical problems that are at present impractical of solution. To conserve space, it is necessary that the maximum number of pulses be recorded in each linear inch of the medium without loss of distinctness or objectionable blending of one pulse with another. Investigations of the magnetizing current, pulse width, and frequency as related to this blending, by using wire as the recording medium, were therefore initiated at this Bureau. During the studies it became evident that useful information could be obtained if the length of the recorded pulses could be directly determined. An interesting, yet simple, technique was developed by Irvin L. Cooter of the magnetic measurements laboratory, in cooperation with members of the electronic computer laboratory, for visually observing the external field patterns surrounding minute permanent magnets.

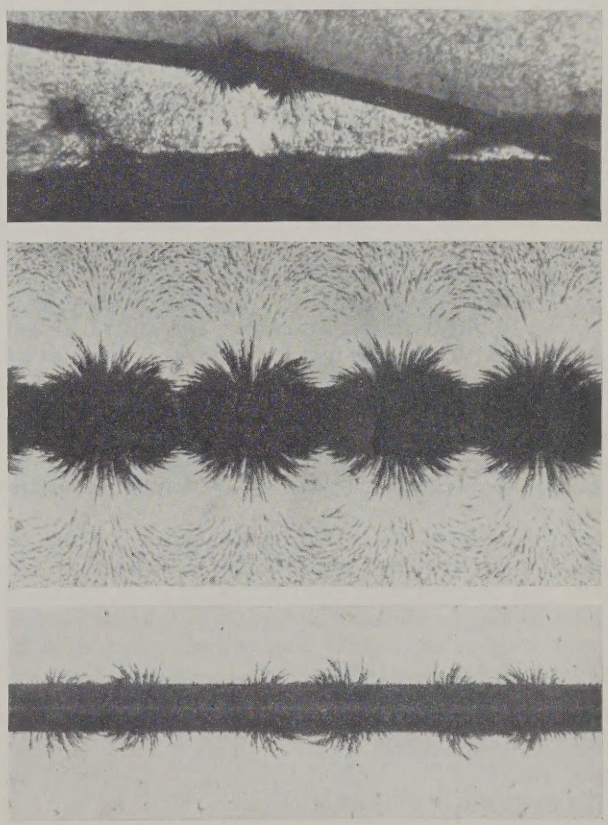
When a moving wire is magnetized in the recording head by a magnetic field produced by current pulses of short duration (a few microseconds), a series of small permanent magnets is produced in the wire. In order to minimize the effect of wire speed on the length of the magnet, speeds not in excess of 8 to 12 inches per second were used. This meant that during the period of the magnetizing pulse the wire moved only 0.0001 to 0.0002 inch.

A wire retaining magnetically recorded pulses is similar to a succession of short cylindrical magnets laid in a line and connected end to end by a permeable medium. For the apparatus used in this investigation, the distance between the poles of the permanent magnets was found to be of the order of 0.010 inch. In order to map the magnetic fields surrounding these minute magnets, it is obvious that special techniques are required.

It is well known from elementary physics that iron filings, when scattered about a magnet, are not only attracted to the magnet but also arrange themselves in definite lines corresponding to the direction of the magnetic flux. These lines of iron filings are said to "map" the magnetic field. In a similar way the magnetic field of extremely small magnets can be mapped if the iron particles are sufficiently small and proper techniques are used in producing the pattern. After considerable experimentation with various magnetic particles and vehicles, it was found that carbonyl iron particles (approximately 0.0001 inch in diameter) suspended in a light oil are suitable for providing the necessary fineness of pattern detail, when using a magnification of 150 diameters.

Since the dimensions of these cylindrical magnets are very small (0.005 inch in diameter by 0.010 inch long) and the magnetic forces involved are extremely weak, considerable care must be exercised in order to obtain the pattern. Techniques were therefore developed for mounting the wire, producing the patterns, magnifying, and photographing the wire and pattern.

The wire is magnetized by current pulses in the usual manner with a standard commercial recording head. Then the wire is stretched across a clean glass plate with sufficient tension to hold it tightly to the glass surface. A few drops of melted flake shellac are used to cement the wire to the glass plate at two points approximately 3 inches apart. A 3-inch section affords an ample number of pulses for study. The glass plate with the attached wire is then placed on the stage of a standard contour-measuring projector. The image of the wire, illuminated by a light underneath, is projected onto a vertical screen at a magnification of 150 diameters by a lens and mirror system. The vertical screen is an 8- by 10-inch ground glass plate upon which the



**External field patterns surrounding the minute permanent magnets produced when a moving wire is magnetized by a recording head may be observed by use of a simple technique worked out in NBS laboratories. Patterns illustrating the technique include: (top) magnetized wire removed from magnetizing head, the solid black mass below the wire; (center) sine wave, 35 cycles per inch; (bottom) three pulses of alternate polarity.**

image of the wire is focused and the formation of the pattern observed. After the pattern is formed, the ground glass plate is replaced with film and the pattern photographed. A camera shutter built into the lens mount controls the exposure time.

A drop of iron-particle suspension is placed on the wire, and the resulting formation of the pattern is observed on the screen. If oil of the correct density and viscosity has been selected for the size and shape of the iron particles, the particles settle at the proper rate to give a definite and distinct pattern of the external field. Particles in the strongest field (near the wire) are attracted and adhere to the magnetized portion of the wire, and in a few minutes build up a pattern extending out a distance approximately one-half the full diameter of the wire. The portion of the pattern that is produced on the glass forms more slowly, since the magnetic forces acting there are much smaller. Usually a satisfactory pattern will be produced in about 30 minutes. During the entire settling process and subsequent photographing, precautions must be taken to prevent any jarring or movement of the glass plate.

# Unification of American and British Screw Thread Standards

Delegates and representatives from Government and industry of Canada, the United Kingdom, and the United States met at the National Bureau of Standards on November 18, 1948, to sign an accord on unification of the American and British standard systems of screw threads. The accord, representing the culmination of 30 years of effort among the three Nations, affirms the unification presented in revised publications of the Interdepartmental Screw Thread Committee of the United States of America, and of the British Standards Institution, the Canadian Standards Association, and the American Standards Association. These documents fulfill all the requirements for general interchangeability of threaded products made in the three Nations. Not only is the accord of major significance in expanding and facilitating commerce between the cooperating Nations, but it is also an important step toward the further development and extension of unifying standards in other fields of engineering practice.

Signers of the accord, representing the three Nations involved, were C. D. Howe, Minister of Trade and Commerce, Canada; J. G. Morrow, Chairman, Canadian Standards Association; T. R. B. Sanders, Ministry of Supply, United Kingdom; Percy Good, Director, British Standards Institution; Sir Ewart Smith, representing British Industry; Dr. E. U. Condon, Director of the National Bureau of Standards and Chairman of the Interdepartmental Screw Thread Committee of the United States; F. P. Tisch, Vice Chairman, Sectional Committee, B1, on the Standardization and Unification of Screw Threads, American Standards Association; and W. L. Batt, Chairman, Sponsors Council of the United States and United Kingdom on the Unification of Screw Threads.

In the United States, Subcommittee No. 1 (Paul J. DesJardins, Chairman) of the ASA Sectional Committee, was charged with the revision of ASA Standard B1.1–1935, American Standard Screw Threads, and with embodying therein the unified screw threads. This task has been accomplished with the active cooperation of the Interdepartmental Screw Thread Committee and the National Bureau of Standards. The Sectional Committee, organized under the procedure of the American Standards Association, is sponsored by the American Society of Mechanical Engineers and the Society of Automotive Engineers. The unified standards will be made effective in the Departments of the U. S. Government by inclusion in the next revision of National Bureau of Standards Handbook H28, *Screw Thread Standards for Federal Services.*

In the United Kingdom, a draft of the Provisional British Standard Unified Threads was prepared by the British Standards Institution in conjunction with the Inter-Services Technical Panel. The Canadians, with extensive commercial ties to both the United Kingdom and the United States, participated in the joint conferences and agreed to accept the standard developed by the British and American Governments.

The significance of the accord is patent in the field of commerce. Almost all mechanisms and structures of modern technologic society are held together by fasteners such as bolts, nuts, screws, and rivets. To cite an extreme case, for example, there are 122,000 screws in one type of airplane. Economical production in the automotive, aircraft, agricultural implement, and other industries using assembly-line methods requires not only a steady supply of components but also that the components, including large numbers of fasteners, be interchangeable so that they can be fitted together without selection, subsequent machining, or hand-fitting of any kind.

In the past, international trade in mechanisms of all kinds has been seriously handicapped by the lack of interchangeability of screw-thread parts. This has required the manufacturing nation also to supply and distribute such parts along with the equipment it wishes to market in a foreign area. Furthermore, the question of the availability of such parts has acted as a psychological deterrent to purchasers of products from other nations. These limitations on the international commerce of Canada, the United Kingdom, and the United States will gradually disappear as the unified standards are acted upon by the industries of the three Nations in the ensuing years.

During the First World War, the experience of the allied American and British armed forces revealed that the lack of interchangeability of American and British screw threads was a serious problem. In World War II, the high degree of mechanization of all military forces made the problem even more critical.

# Declaration of Accord

with respect to the

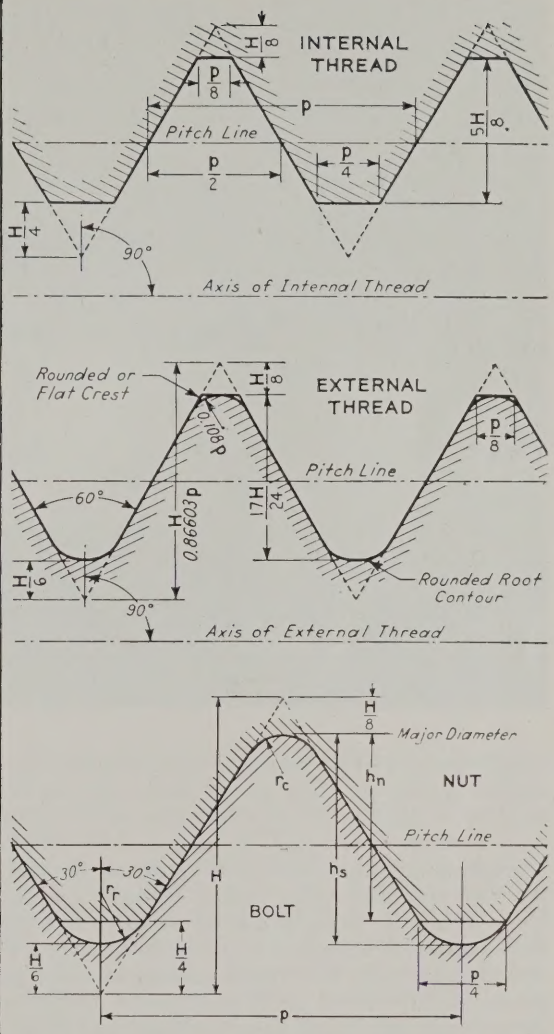
## Unification of Screw Threads

It is hereby declared that the undersigned, representatives of their Government and Industry Bodies, charged with the development of standards for screw threads, Agree that the standards for the Unified Screw Threads given in the publications of the Committees of the British Standards Institution, Canadian Standards Association, American Standards Association and of the Interdepartmental Screw Thread Committee fulfill all of the basic requirements for general interchangeability of threaded products made in accordance with any of these standards.

The Bodies noted above will maintain continuous cooperation in the further development and extension of these standards.

Signed in Washington, D. C., this 18th day of November, 1948, at the National Bureau of Standards of the United States.

| | |
|---|---|
| | Ministry of Trade and Commerce, Dominion of Canada |
| | Canadian Standards Association |
| | Ministry of Supply, United Kingdom |
| | British Standards Institution |
| | Representative of British Industry |
| | National Bureau of Standards<br>U. S. Department of Commerce<br>Interdepartmental Screw Thread Committee |
| | American Standards Association<br>The American Society of Mechanical Engineers<br>Society of Automotive Engineers |
| | Sponsors Council of United States and United Kingdom on the Unification of Screw Threads |




**The accord for the unification of screw threads (left) provides for the general interchangeability of threaded parts throughout the United Kingdom, Canada, and the United States. Optional details of thread form (right) include the American preferred form of internal thread (above) with flat crests and roots, the unified external thread (center) with rounded roots and either rounded or flat crests, and the British preferred form (below) with rounded root contours and flat crested internal thread. ($H=0.866025p$; $r_c=0.108253p$; $r_r=0.144338p$).**

American industry was required to supply the British with a large volume of war equipment threaded to the British specification. This not only led to considerable delay but was economically disadvantageous. At the same time, American military forces based in England and using equipment with American threads found difficulties in making necessary replacements.

### Technical Basis of the Accord

The three principal characteristics of screw threads are angle and form of thread, pitch (the combinations of diameter and number of threads per inch for the various thread series), and limiting dimensions (the manufacturing tolerances and allowances) for each grade of thread fit.

The British system, originated by Whitworth in 1845, is based on a thread angle of 55 degrees with a thread form having rounded crests and roots. The American system, developed by Sellers in 1864, has a thread angle of 60 degrees with a thread form having flat crests and roots. The number of threads per inch for the various series of thread diameters is the same in both systems, with the exception of the half-inch coarse thread. Accurate fits between components having different thread angles are impossible. Moreover, the tolerances and allowances vary in the two systems.

The present unification agreement provides a 60-degree angle and a rounded root for screw threads. The crest of the external thread may be flat, as preferred in American practice, or rounded, as preferred by the British. The number of threads per inch for the various series of thread diameters has been unified, and the limiting dimensions for three grades of fit between mating parts have been agreed upon. The sizes,

**The Joint Session on the Unification of Screw Threads, mark screw-thread standard for Canada, the United Kingdom, and and industry of the three Nations. Left to right at the speak T. R. B. Sanders, British Ministry of Supply; Sir Ewart Smith Trade and Commerce; Sir Oliver Franks, British Ambassador; don, Chairman of the Interdepartmental Screw Thread Comm Standards, who acted as Co-Chairman of the Session; Hume tive Committee, American Standards Association, also Co-Chair William L. Batt, Chairman, the Sponsors Council of the Unite G. Morrow, Chairman, Canadian Standards Association; and Frank P. Tisch, Vice-Chairman of Sectional Committee B1 on Standards Association, does not appear in the picture.**

the threads per inch, and the basic dimensions of the unified coarse and fine thread series that have been adopted, together with agreements that (1) the minimum internal thread shall be basic and the allowances (or minimum clearances on the flanks of the threads) shall be applied to the external threads and (2) tolerances shall be in the minus direction on the external thread and plus direction on the internal thread, assure interchangeability of screw-thread parts and threaded products. Threaded parts of standard diameters and threads per inch, made in accordance with these principles, will always assemble freely.

There is, however, a further degree of interchangeability attained by agreements on the numerical values for allowances and tolerances, thereby setting limits to the least and greatest amounts of looseness between mating parts. Such agreement provides for identity of sizes (or interchangeability of use) of screw-thread gages used in the different countries for controlling the limits of size of the threads.

The three grades of fit are designated by the numerals 1, 2, and 3, with letters A for external threads and B for internal threads. Classes 2A and 2B, constituting the second or medium grade, are those which have become rather widely known by the class designations A and B during the course of their development by industry during the past few years. Class 2A is the recognized standard in the United States for bolts and screws and class 2B for nuts. They are also suitable for a wide variety of other applications.

The basic formula, from which allowances on all diameters and tolerances on pitch diameter are derived, is

$$\text{Tolerance (or allowance)} = C(0.0015\sqrt[3]{D} + 0.0015\sqrt{L_e} + 0.015\sqrt[1.5]{p}).$$

In this formula, $C$ is a factor that differs with the allowance or tolerance for each class, $D$ is the basic major diameter, $L_e$ is the length of engagement, and $p$ is the pitch. The formula is based on the accuracy of present-day threading practice, and is applicable to all reasonable combinations of diameter, pitch, and length of engagement.

As suggested in the above discussion, a few details remain to be completed. An Editing Subcommittee, consisting of representatives of the three Nations, was appointed by Sectional Committee B1 on the Standardization and Unification of Screw Threads at its meeting on November 18, 1948. This subcommittee was authorized to resolve, within specified limitations, the differences that remain. Any agreements reached will be incorporated in the American standard without further formal action by the three Governments.

The Unified Screw Thread Standard was formulated through five major and several informal conferences of representatives of the countries concerned. In July 1918, the Congress of the United States authorized the

**e culmination of the technical development of a common nited States, was attended by delegations from Government le are: Percy Good, Director, British Standards Institution; senting British Industry; C. D. Howe, Canadian Minister of Sawyer, U. S. Secretary of Commerce; Dr. Edward U. Con- of the United States and Director of the National Bureau of Canadian Ambassador; Howard Coonley, Chairman, Execu- the Session; Donald Carpenter, Chairman, Munitions Board; es-United Kingdom on Unification of Screw Threads; James R. Miller of the Interdepartmental Screw Thread Committee. andardization and Unification of Screw Threads, American**

appointment of the National Screw Thread Commission, with the Director of the National Bureau of Standards as chairman, to investigate and promulgate standards for screw threads. One year later, and after a thorough study of screw-thread practice in this country, the Commission conferred with British and French engineers and manufacturers of screw-thread products, for the purpose of discussing the tentative report that it had prepared in the hope that it might serve as a basis for international standardization. No definite agreements were reached, but the need for continued study was recognized.

In 1926 a further attempt was made to unify the British Standard Whitworth Thread, having an angle of 55 degrees, and the American National Thread, having an angle of 60 degrees, when a British mission visited the United States and proposed a basic thread angle of 57½ degrees. The compromise was not considered acceptable.

In 1943 a British mission visited the United States, at the invitation of the Combined Production and Resources Board. Canadian representatives were also invited to participate in the discussions, which resulted in notable progress on projects of immediate concern. In August to September 1944 a joint United States-Canadian group, sent to London by the same Board, conferred with committees of the British Standards Institution.

In September to October 1945, under the auspices of the same Board, a conference on Unification of Engineering Standards was held in Ottawa, Canada. At this conference a unified form of thread having a 60-degree angle, together with standard sizes and pitches, was accepted. The foundation was thus laid for the standards to be agreed on, but a vast amount of work remained to be done in developing and establishing grades of fit and corresponding classes of tolerances and allowances. When a British delegation visited the United States in July 1948, the basic mathematical formulas for such tolerances and allowances were tentatively agreed upon and later ratified by correspondence, thus making possible the completion of the standards at the November 18 meeting.

*Values of the factor C for allowances and pitch-diameter tolerances*

| Class | Allowances [a] | Pitch-diameter tolerance [b] |
|---|---|---|
| 1A | 0.450 or 0.300 | 1.500 |
| 1B | ..... | 1.950 |
| 2A | .300 | 1.000 |
| 2B | ..... | 1.300 |
| 3A | .000 | 0.750 |
| 3B | ..... | .975 |

[a] By agreement, allowances are applied to external threads only.
[b] Values of *C* for internal threads are 30 percent greater than for external threads, to provide for relative difficulties of manufacture.

## Future Developments

In one sense, the present accord marks the culmination of 30 years of work by the three Nations toward the establishment of unification. In another sense, it marks but a beginning of the realization of unification. Purchases by the three Governments will be based on the new standards, but industrial use within the normal commerce of each of the Nations will require a transformation of industrial practices, involving considerations of engineering, design, tooling, and production.

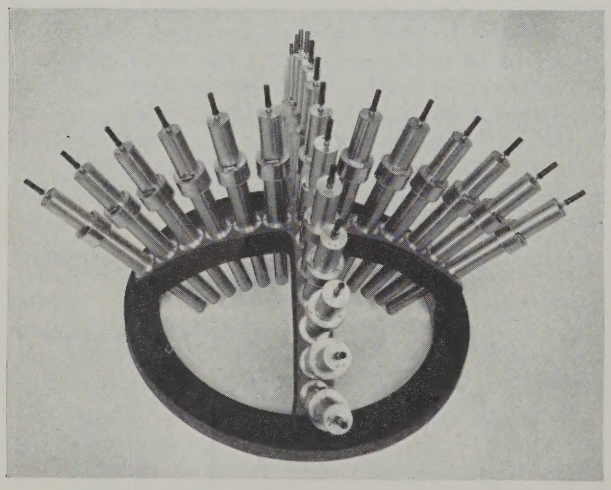
At the same time, continued screw-thread research is important. A screw thread is one of the more complex regular geometrical forms. There are so many variables that enter into the design of a satisfactory threaded fastener that most of the knowledge applied in such design has been empirical rather than theoretical. An immediate result of the Ottawa Conference in 1945 was the initiation of a joint program of research to be carried out by the National Bureau of Standards of the United States, the National Physical Laboratory of England, and the National Research Council of Canada.

The present accord calls for continuance of cooperation in the field of screw-thread standardization. Such cooperation has two aspects: First, extension of the unification to the other English-speaking nations (all of which use the English system of measurement in manufacture); and, second, the continued development of standards. Standards are not static, and they must keep pace with improvements in materials and methods of production and inspection developed in industry. Reduction of the varieties of fasteners is one of the possibilities that may result from further studies.

Moreover, the present accord pertains to the most commonly used type of screw thread. Other important types of screw threads remain to be standardized. In the case of Acme and Buttress threads the unification of standards has reached an advanced stage. Further, standardization of drafting-room practices within the countries and their unification among the countries are essential if there is to be an interchangeability of blueprints and production drawings. In these and related fields, the three Governments and the respective standardization organizations are carrying on continuing programs.

# New Precision Camera Calibrator

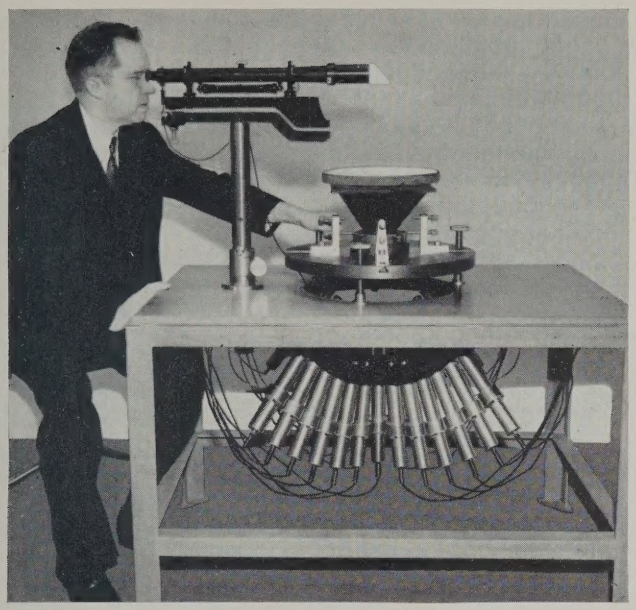
Calibration of precision airplane-mapping cameras is greatly facilitated by a new device developed by Dr. F. E. Washer and F. A. Case of the Bureau's optical instruments laboratory. Designed specifically for this purpose, the calibrator overcomes several deficiencies of the instrument that has previously been used; for example, it requires but one negative, whereas the older method requires four. It is also much more compact and incorporates a number of other unusual design features.

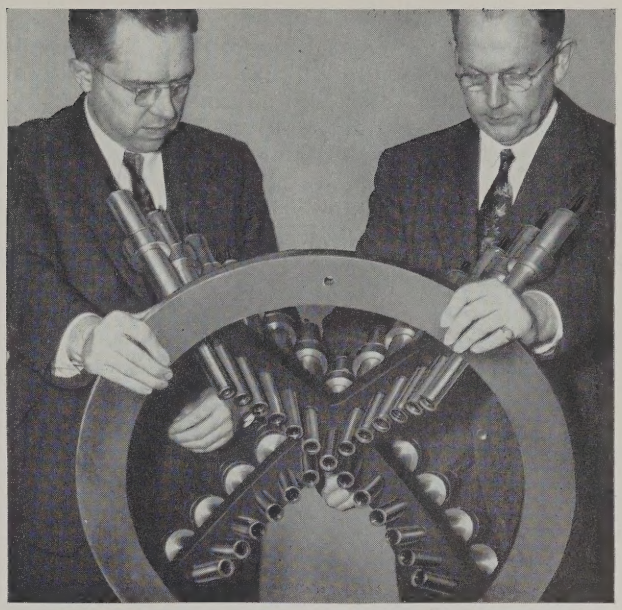


**Heart of the Bureau's new instrument for calibrating precision mapping cameras is the bank of 25 collimators arranged in the form of a cross. The central collimator points vertically, with the remaining 24 spaced at 7.5° intervals. They are mounted in a special casting whose inner and outer envelopes are hemispheres.**

As the science of photogrammetry, with its exacting requirements for aerial camera lenses, has advanced within the past few decades, Bureau scientists have been constantly improving the methods for measuring the characteristics of these lenses, including their focal lengths, distortion, and resolving power. According to present specifications, prepared jointly by the American Society of Photogrammetry and the National Bureau of Standards, a precision mapping camera must be provided with a lens that complies with a number of very stringent requirements. Furthermore, it must incorporate such features as a fixed focal plane; rigid connection of lens, focal plane, and camera cone into a single unit; and collimation index markers so located that lines joining opposite pairs of markers intersect at an angle of 90° $\pm 1$ minute with the intersection marking the principal point within $\pm 0.03$ mm.

At first these measurements were made visually by means of a visual optical bench. Later, a new precision camera was constructed for conducting the tests under conditions more nearly approximating the conditions of use. Equivalent focal length, distortion, and resolving power are determined from measurements made on a negative produced by the lens under test. This instrument has also been adapted to the calibration of the lens-cone combination of the improved type of precision mapping cameras. The method, however, possesses several serious deficiencies: (1) As suggested previously, four negatives are required, a time-consuming operation, (2) different sizes and shapes of the various makes of cameras cause difficulties in mounting them properly for test, and (3) the entire field cannot be covered with a single photograph. The new calibrator was therefore designed to remedy these difficulties.





**The new calibrator for precision cameras consists essentially of the collimator bank, a camera holder, and an automatic collimating telescope whose axis is bent 90° by a prism in front of the objective. The camera is mounted on its holder to point vertically downward through the central opening and thus permit the light from the 25 collimators to reach the camera lens. Images of the targets are shown every 7½° along each diagonal of the finished negative, with collimation markers registered on the sides.**

A collimator bank, which consists of 25 collimators arranged in the form of a cross, is the heart of the instrument. It is mounted beneath a table and centered below a large circular opening in the table top. The central collimator points vertically upward, and the remaining collimators are spaced at 7.5° intervals along the four arms of the cross from 0° to 45°. Departure from the 5° interval used in the lens-testing camera is necessitated by space limitations. The collimators are mounted in a special casting whose inner and outer envelopes are hemispheres. Accordingly the collimator axes that are normal to the hemispherical surfaces point toward the center of curvature. Accuracy of pointing depends to a large extent upon the accuracy of counterbored holes and flanges by which the collimators are mounted. However, small deviations can be corrected by small movements of the targets mounted in the focal planes of the collimator objectives. These adjustments are made with capstan screws, so arranged as to afford complete translational freedom of the reticle. After adjustments, clamping by appropriate screws guards against any subsequent movement.

The collimators are of the fixed-focus type with the tubes cut to the proper length so that each reticle lies in the focal plane of the corresponding objective. To guard the collimators against disturbance, the lamp housings are independently mounted on the arms of the cross. For simplicity the lamp house completely surrounds the target end of the collimator but does not touch it at any point. A 6-volt frosted flashlight bulb serves to illuminate the reticle. Provision is made for the insertion of a filter and a glass diffusing screen between the lamp and target.

The camera is pointed vertically downward, mounted on a camera holder that consists of a tripod placed over the opening in the table. The central opening permits the light from the 25 collimators to reach the camera lens. The focal plane of the camera can be adjusted to normality with the axis of the central collimator with the aid of adjusting screws on the tripod and an autocollimating telescope whose axis is bent 90° by a prism mounted in front of the objective. This arrangement for mounting the camera offers several advantages: (1) Regardless of the type and various irregular protuberances, most aerial cameras can be readily mounted and supported with the lens directed downward; (2) the camera is held in position by gravity, with lateral movement prevented by the movable stops; (3) the glass plate used for autocollimating can be a heavy optical plane parallel, held in place on the focal plane of the camera by gravity; and (4) the photographic plate can be similarly laid on the focal plane, and a heavy weight serves to hold it in place while tending to flatten it during the photographic exposure.

The finished negative shows the images of the targets every 7.5° from the center to the corner along each diagonal. The collimation markers are registered on the sides of the negative, so that there is little likelihood of the target images being spoiled by the light that registers the markers.

The registering of images at known angular separation from the axis out to 45° increases by a factor of 10 the accuracy of determining the shift of the principal point resulting from prism effect. In addition, it should be possible to measure the so-called tangential distortion, which is somewhat of a problem at present. Resolution charts are included as a part of the

targets, so that some information on the definition from the center to the corners of the negative can be obtained during the calibration. The small diameter of the collimated beams precludes the possibility of testing the definition at aperture greater than $f/8$ for a 6-inch lens. However, examination of the imagery will definitely show if there are any marked differences in the definition along the two diagonals.

A new resolution chart has been prepared for this instrument. The line spacings in the targets vary in steps equal to the fourth root of 2 and will permit evaluation of the resolving power over the range from 4 to 130 lines per millimeter for a 6-inch lens. Circle targets are included so that comparison between line and circle targets can be studied.

It must be emphasized that this instrument is primarily intended as a pointing instrument in the sense that it provides 25 beams of parallel light from known directions. The information derived from it will therefore be mainly of a directional nature, and will include data on the uniformity or lack of uniformity in the distortion characteristics of the lens-cone combination. It will permit more rapid and more accurate location of the principal point, together with a determination of the equivalent focal length of the lens as mounted in the camera. It will provide quantitative information on the magnitude of the prism effect and the effect of tangential distortion. Moreover, it will provide all this information on a single negative, so avoiding possible changes that result from small movements occurring between successive exposures. It will provide a more stable support for the camera during test, and also greater versatility in the types of camera that can be tested.

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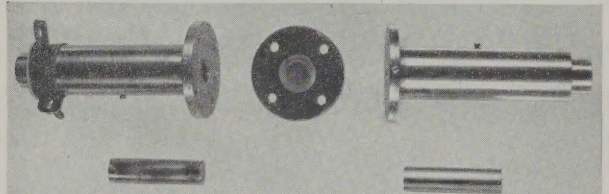
# Worker Consistometer for Lubricating Greases

Investigations of the effect of mechanical working on the physical properties of lubricating greases by S. A. McKee and H. S. White of the Bureau's lubrication laboratory have resulted in development of an apparatus [2] that works the grease and measures its flow characteristics in the same series of operations. Data obtained with the new worker consistometer indicate that it is a valuable new tool for studying the properties of lubricating greases. Principal advantages are its flexibility, wide range of shear and consistency measurements, short test cycle, simplicity of design, and, in particular, its provision for characteristic flow data while working under controlled conditions. In addition to the application to greases, Bureau engineers have used the apparatus to determine the apparent viscosity of rubber solutions at different rates of shear and temperature.

The worker consistometer is composed essentially of two coaxial steel cylinders mounted vertically with a capillary-type shearing element inserted between them. Close-fitting pistons force the grease through the shearing element in either direction from one cylinder to the other. While making flow measurements, dead weights are used on the down-stroke of the pistons and air pressure on the up-stroke. Provision is also made for automatic mechanical working.



**The major elements of the worker-consistometer are (left to right, top row) upper cylinder, capillary shearing element, lower cylinder, and (below) pistons for each cylinder. The cylinders are made with flanges for bolting together, with the capillary element between them.**

Various shearing elements can be used. They are made by drilling holes (No. 79 drill) in circular steel disks $\frac{1}{4}$ inch thick, giving capillaries $\frac{1}{4}$ inch long and approximately 0.015 inch in diameter. In order to cover a range of consistencies, one element has one hole, a second has ten, and a third, fifty holes. An important advantage is that the series of disks provides elements with different multiples of the same size capillaries for all grades of greases. This eliminates the effect of differing capillary dimensions in the comparison of non-Newtonian greases of different consistencies.

The cylinders have a nominal bore of $\frac{1}{2}$ inch and a length of $3\frac{7}{8}$ inches, and the hardened-steel pistons are $1\frac{7}{8}$ inches long. One end of each cylinder is provided with a flange for bolting them together. The disk containing the shearing element is inserted between the cylinders. The diametrical clearance between a piston and its mating cylinder is held to a few ten-thousandths of an inch. The assembly of cylinders, pistons, and shearing element is enclosed in a vertical $7\frac{1}{2}$-inch steel tube, which in turn is encased in an electric heating coil. Mounted below the lower supporting flange is a brass air cylinder complete with leather-cup piston and rod. The upper end of the rod contacts the lower piston of the worker. Load is applied to the upper piston through a yoke provided with a pan for weights. Thermocouples mounted on each of the two cylinders and on the disk of the shearing ele-

[2] For further technical details, see ASTM Bulletin 153, p. 90 (August 1948).

ment measure the temperature, which is controlled by mercury-in-glass thermal regulators.

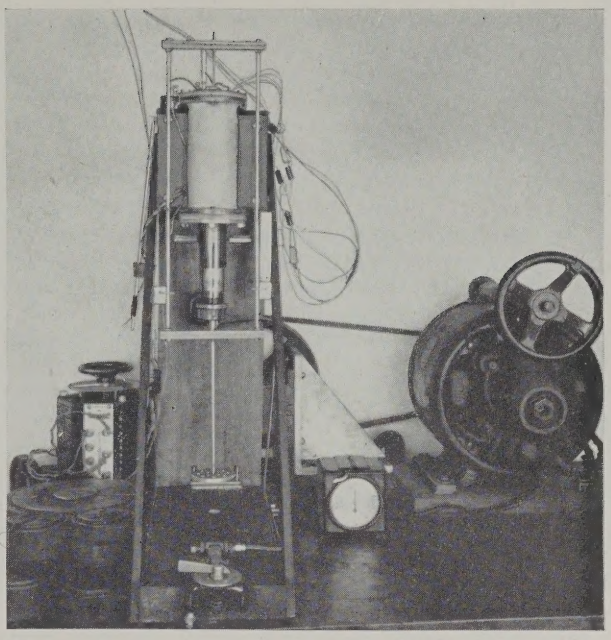
In operation, the upper cylinder is filled with 2 inches (about 6.6 cubic centimeters) of grease and the apparatus is assembled and placed in position in the tubing support. Weights applied to the yoke drive the upper piston down, thus forcing the grease through the shearing element. A pointer on the yoke moving along a steel scale indicates the movement of the grease, and the time is observed for the middle 1 inch of the 2 inches of travel. A three-way valve then admits air under pressure to the brass cylinder, thus forcing the pistons and grease upward. At the top of the stroke, the air pressure is released and the cycle of operations repeated, by using the same or a different load on the yoke. A motor-driven lever can be attached to the yoke and air piston rod for automatic working when not timing the rate of flow.

In calibration tests with the apparatus the applicability of the Poiseuille equation was demonstrated. This is evident from the straight-line relationship obtained when $\eta/t$, the absolute viscosity ($\eta$) of the standard viscosity oil at test temperature divided by the time of flow ($t$), is plotted against $p$, the pressure exerted by the weights moving the upper piston. The data indicate that the effect of temperature, over the range covered (76° to 300° F), is relatively small and can be neglected.

The resistance to the motion of the pistons is in part caused by the shearing of the oil in the clearance spaces between the pistons and the walls of the cylinders. This effect was determined by making direct measurements of the rate of motion of the pistons under various loads when the apparatus was filled with oil but without the shearing element between the cylinders. The results were in good agreement with computations of the viscous shear based on measurements of the clearances and the areas under shear. The kinetic-energy correction is appreciable only with the 1-hole disk when operating at relatively high rates of flow, that is, when the test cycle is completed in less than 10 seconds.

In making a test with the apparatus, flow observations are taken successively at each of a number of loads, and the series repeated until several measurements have been made at each load. The motor-driven lever is then attached and the apparatus operated automatically for a number of passes. The sequence of flow measurements and automatic working are continued for the duration of the test. The test data may be shown graphically by plotting the rate of flow observed at each load against the number of passes. These curves may then be used to obtain flow-pressure curves (rate of flow against pressure) for any given pass through the shearing elements. If desired, the values of the intersections of these curves with a horizontal line representing a given rate of flow may be used to compute the effect of working upon the apparent viscosity of the grease at that rate of flow.

The effects of working upon the flow of the greases at a given load varied with the different greases investigated; with some the flow increased markedly whereas with others it decreased. There was also an indication



**The worker-consistometer measures the flow characteristics of lubricating greases and works the sample in the same operation. Weights on the pan of the yoke force the grease downward between cylinders and through the capillary shearing element (enclosed in insulated tube, upper left). Compressed air forces it upward.**

that changes in the rate of working some greases affect the flow characteristics of the grease. For example, the flow at a given load of one sodium-soap grease increased rather slowly when working at a comparatively low rate, but the increase was much more rapid at a higher rate. In another case the flow increased with working at a low rate, but at a higher rate it increased at the onset of working, then reversed itself and decreased on further working. Observations at temperatures of 100°, 200°, and 300° F indicate that temperature also had an effect upon the variation of flow with working. For instance, an increase in the test temperature lowered the rate of working necessary to produce the reversal for the sodium-soap grease mentioned above.

The possible rates of shear using the apparatus cover a rather wide range, from about 10 to 100,000 reciprocal seconds. During periods of automatic working the rate of shear has been as high as about 180,000 reciprocal seconds.

Experimentation at the Bureau has been directed mainly toward demonstrating the applicability of the apparatus. Besides its chief advantage of providing flow characteristics as the grease is being worked, the consistometer permits a complete test series at constant temperature. High rates of shear are provided by the small diameter capillary. The multihole disks give sufficient flexibility to cover wide ranges of rates of shear and consistency—advantageous from a mechanical working standpoint. The small sample required for a test shortens the time necessary to bring the grease to the test temperature. Furthermore, the simplicity

of design leads to a facility of cleaning and charging that is significantly time saving.

In addition to its application in the field of lubricating-grease technology, the development appears applicable to any rheological problem where a wide range of consistencies or rates of shear, or the effects of mechanical working, are of interest. For example, the apparatus has been used to measure the apparent viscosity of 5- to 30-percent solutions of rubber in *o*-dichlorobenzene over a wide range of rates of shear, a research project for the Office of Rubber Reserve, Reconstruction Finance Corporation. Thus, this apparatus that was originally intended for testing and investigations of lubricating greases, will now be used for investigations of the structure of rubber and other high-polymer molecules. An index, obtained through viscosity measurements, is being sought for determining the degree of branching of synthetic-rubber molecules and the extent of cross linking of the different long-chain rubber molecules. These structural properties influence the quality of synthetic rubber as used in manufactured articles.

# NBS Publications

## *Periodicals* [3]

Journal of Research of the National Bureau of Standards, volume 41, number 6, December 1948. (RP1938 to RP1945, inclusive.)

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CRPL-D52. Basic Radio Propagation Predictions for March 1949. Three months in advance. Issued December 1948. 10 cents.

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LC927. House plan services. (Supersedes LC866.)

LC928. List of published material relating to building regulation. (Supersedes LC847.)

LC929. Standards for checking the calibration of spectrophotometers (200 to 100 m$\mu$).

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